GALORATH

Determining The Cost of Bringing Technologies To Maturity

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Multi-Dimensional Assessment of Technology Maturity
9-11 May 2006

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The Case For Improved Methods

Arms Fiascoes Lead to Alarm Inside Pentagon
- New York Times, 8 June 2005

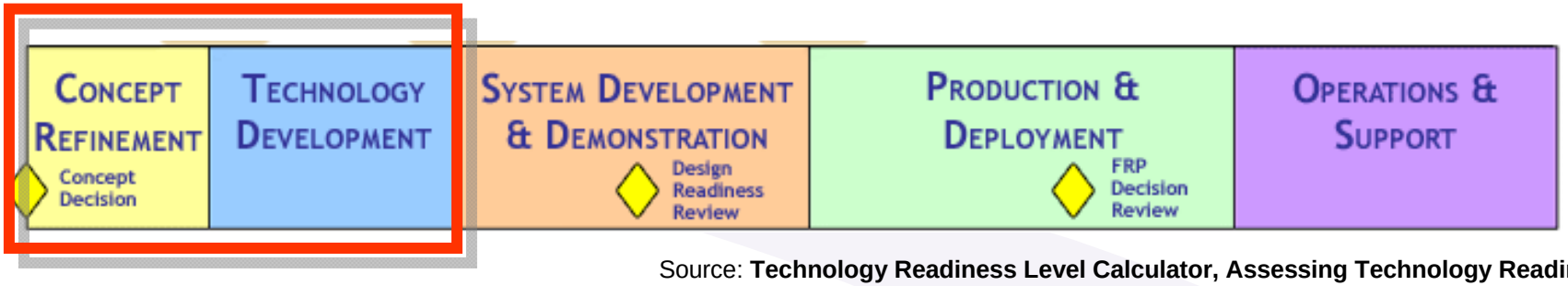




80+ current weapons development projects
Totalling $1.47 trillion, $300B over budget

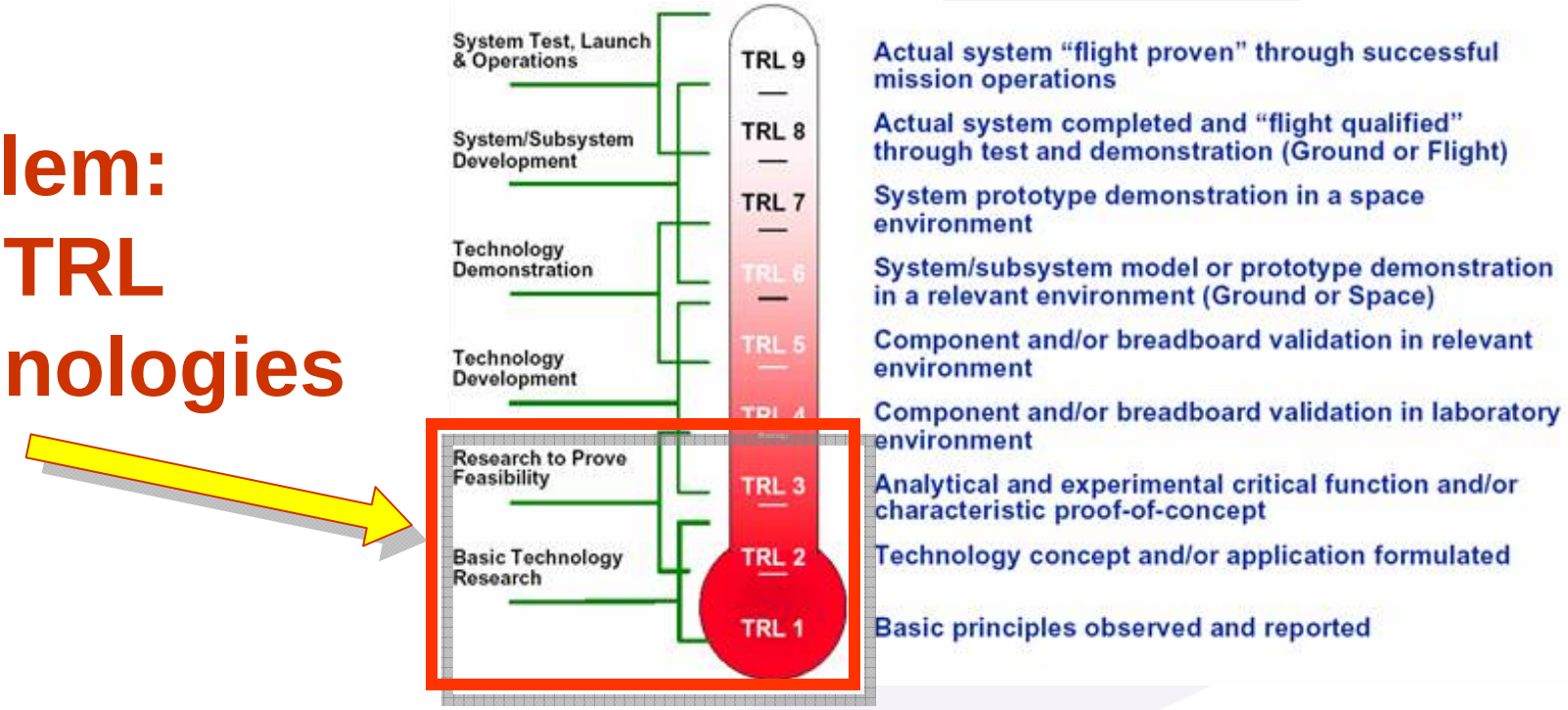

(The services) "push the technology beyond what a contractor is capable of achieving," said (a former weapons-buying official)

Challenge: Costing Immature Projects

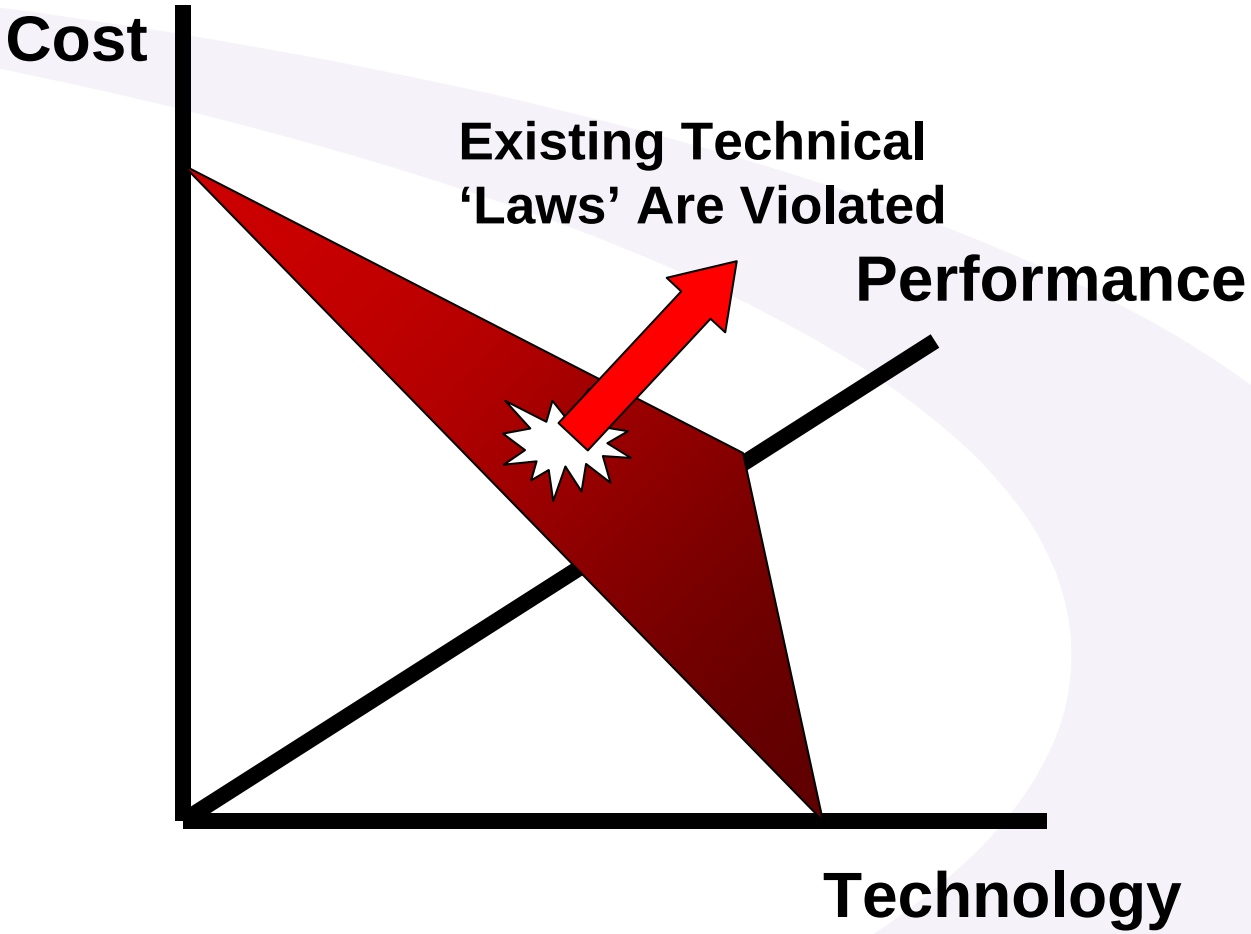


Source: **Technology Readiness Level Calculator, Assessing Technology Readiness & Development Seminar**, William L. Nolte, 28 April 2005

Problem: Low-TRL Technologies

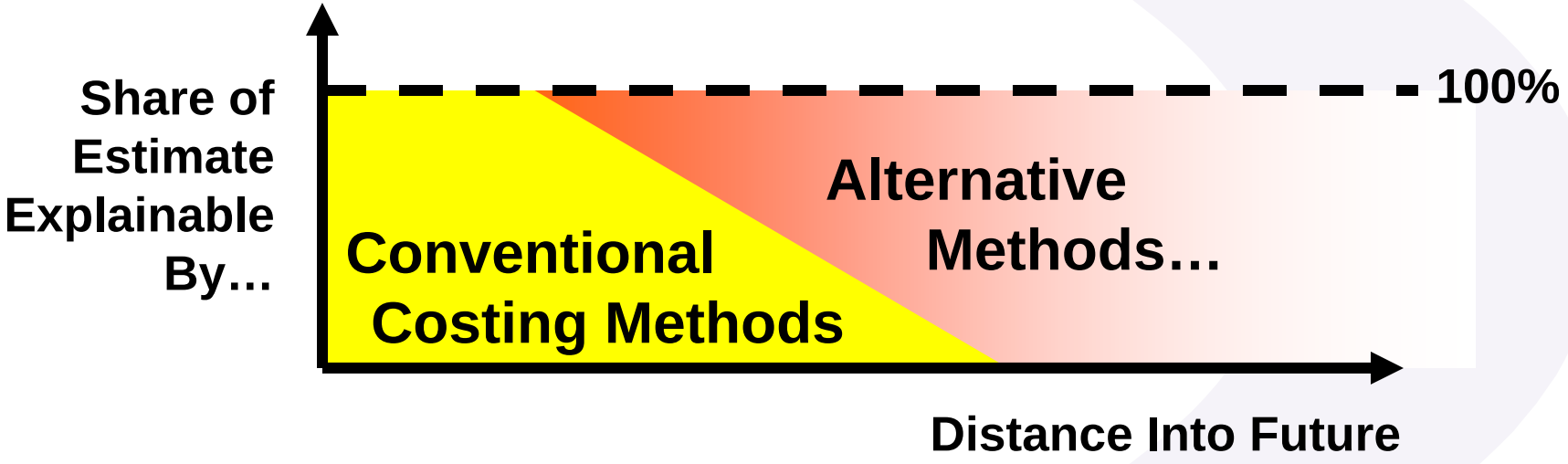


Special Class of Projects: The "Nasty" Ones

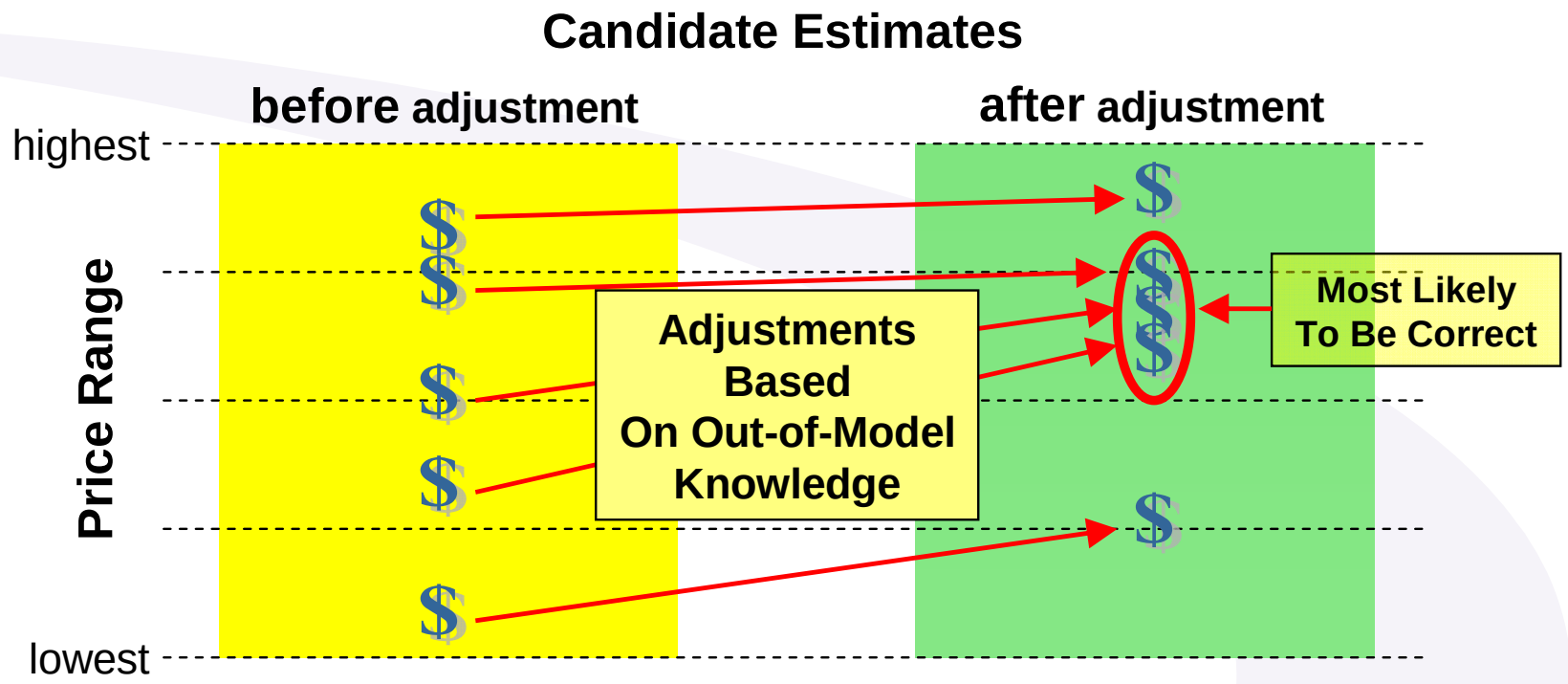


The Trillion $ Question

If new technologies are ventures into the unknown then how can their cost of development be obtained?



Answer: Don't Trust Any One, or Two, or Three Methods



Combining multiple estimating methods:

- **Balances strengths and weaknesses.**
- **Provides cross validation.**
- **Produces a range.**

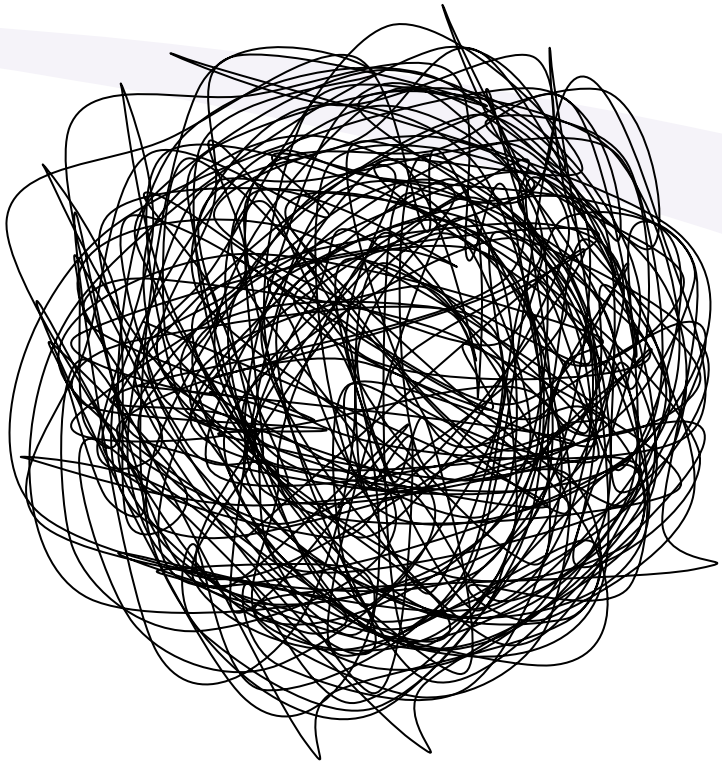
Support for the Meta-Estimating Approach

- **Reduced failure due to data / knowledge scarcity** – candidate estimating methods have purposefully unalike data requirements.
- **Reduced risk** – estimating methods fare differently depending on the scenario.
- **Reduced bias** – estimating methods based on alike data are more likely to yield the same result. If it is a systemically errant result, then it is more likely to be accepted. Using unalike data lessens the chance of this error.
- **More robust** – not all estimating methods need be used every time. Those used would depend on data availability.
- **Built-in validation** – when very different methods agree, there is better support for an estimate.

Candidate Estimating Methods for Advanced Technology Development

Method	Summary	Data Required	Strengths	Potential Weakness
Expert Opinion via Multidimensional Delphi	Combines a classic consensus-building process with a method for improved accuracy in comparative cognitive exercises.	• Sufficient numbers of 'experts' within a given domain • Knowledge of overall costs for similar research programs	• Accuracy proven in many different applications • Works well with limited data	• Shortages of qualified 'experts' • Experts' ignorance of the true cost of research
Model Derived From Past Experience	A parametric model developed from a record of past projects undertaken at research labs.	• Multiyear budget data on past research programs • Some descriptive information about these programs	• Would result in an extremely easy to use parametric model	• Information on research funding may be difficult to obtain
Financial Forensics	Isolates basic R&D costs as a component of product net revenue.	• Breakdown of company cost structure • Share of firm R&D attributable to specific technologies	• May allow recovery of R&D expense for a wide range of products, firms	• Inability to trace back to firms' R&D costs • Past R&D expense may not be indicative of the future
Continuing Cost of Research	Extrapolates future R&D expense given funding levels to-date.	• Knowledge of ongoing costs for related research	• Accurate given steady cost of research over a known future duration	• Past R&D expense may not be indicative of the future • Ignorance of true research costs

Caution: Some Problems Are Just Hard, Not Cutting Edge



Tangled Ball of Simple Stuff – Complex Problem

Simple Ball of Weird Stuff – Cutting Edge Technology

Systems Engineering and Complex Integration Problems

Expert Opinion Via Multidimensional Delphi

Approach

Problem: New technologies' cost is hard for even experts to grasp.

Solution: Mate expert opinion with proven, intuition-based methods.

In this approach:

- **Experts are recruited with knowledge of a variety of technical projects.**
- **They are then given 'reference' projects with known cost and unknown projects that need to be estimated.**
- **The experts are asked to compare all projects, reference vs. unknown, and so on.**
- **After this they are shown each others' comparisons and rationales. These other comparisons will provoke further reflection and encourage people to further refine their choices.**
- **After 2 or 3 rounds, a set of consensus comparisons will exist and then be input to the paired comparisons algorithm, to provide estimates.**

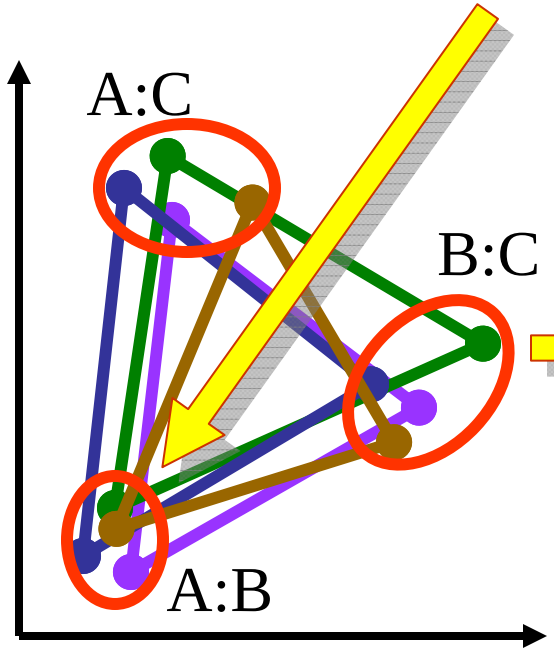
Expert Comparative Assessment Input to AccuScope Paired Comparisons Tool

Expert 1: "I think A is 4 times as big as B."

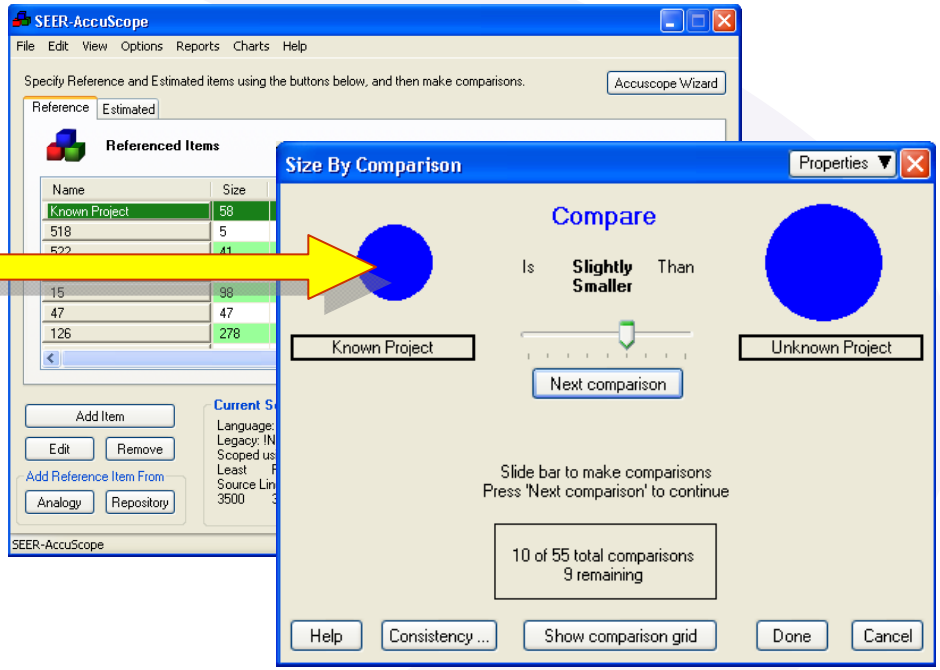
Expert 2: "I think A is 3 times as big as B."

Expert 3: "I think A is 4.5 times as big as B."

>>> Combined assessment: "A is 3.8 times as big as B."



Grouped Expert Comparisons

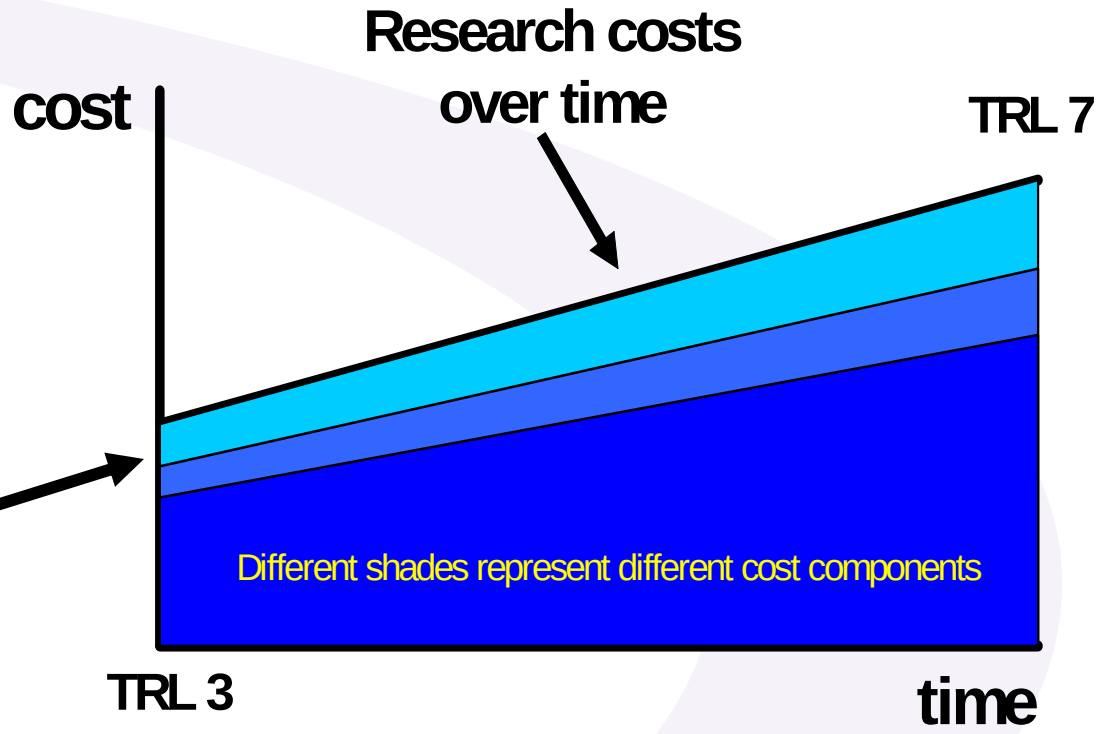


SEER-AccuScope

The 'Continuing Cost of Research' Method

Approach

Project future R&D expenses over period expected to still be needed for a technology's evolution.



Extrapolating from recent past experience.

Already the default method of R&D costing?

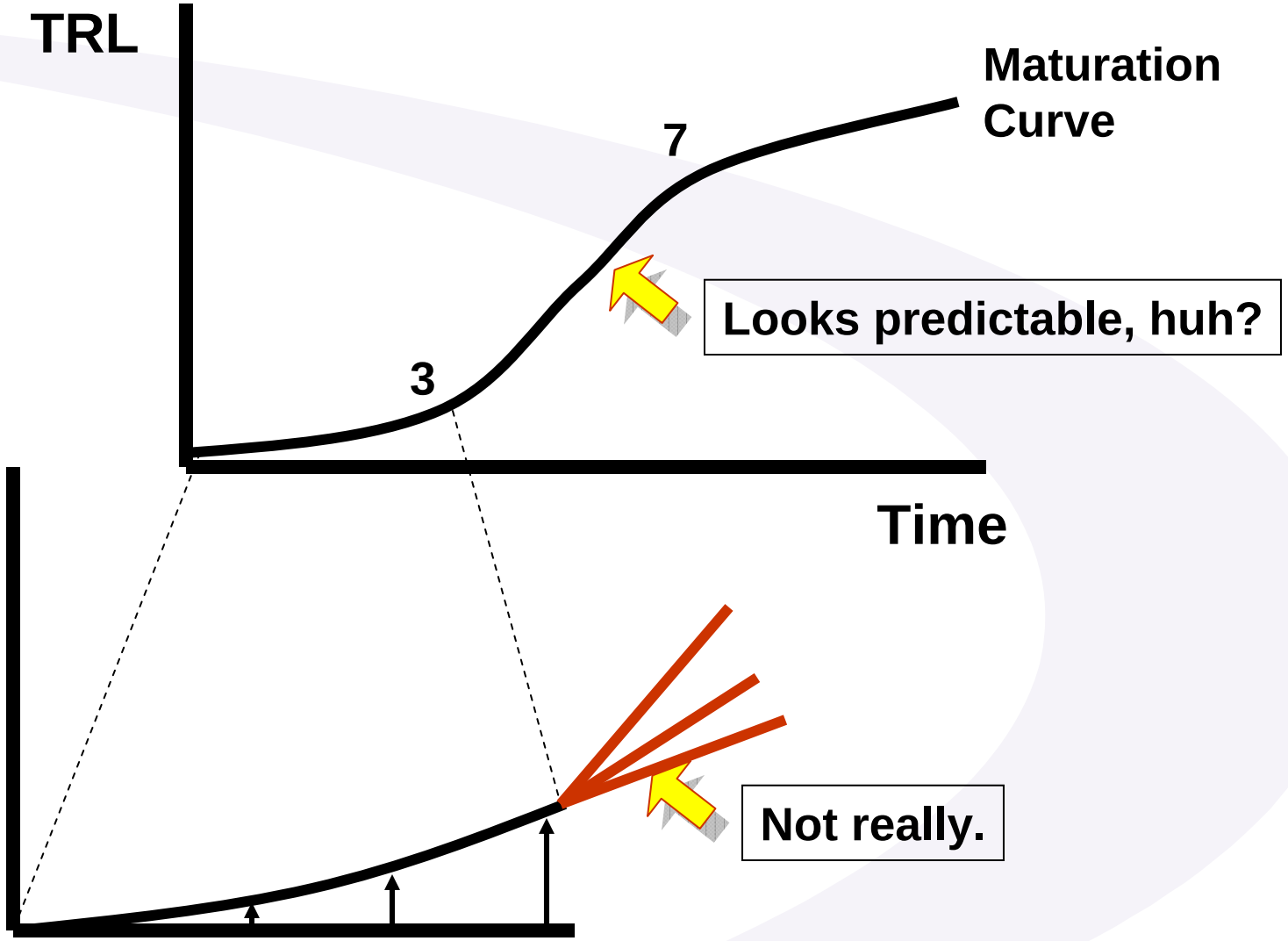
Two Questions To Answer For the 'Continuing Cost of Research' Method

A. **"How many years till TRL 7?"** Can be answered by estimating:
   - The number of years required for previous generational evolutions of the target technology
   - Whether future evolutions will require a similar number of years. It is particularly helpful if the rate of change in the technology can be inferred.

B. **"How much is spent today on yearly R&D?"** Historical costs can be recovered using whatever records necessary, while future costs can be determined by estimating whether costs will remain stable or change due to labor, capital equipment, test, prototype or other needs.

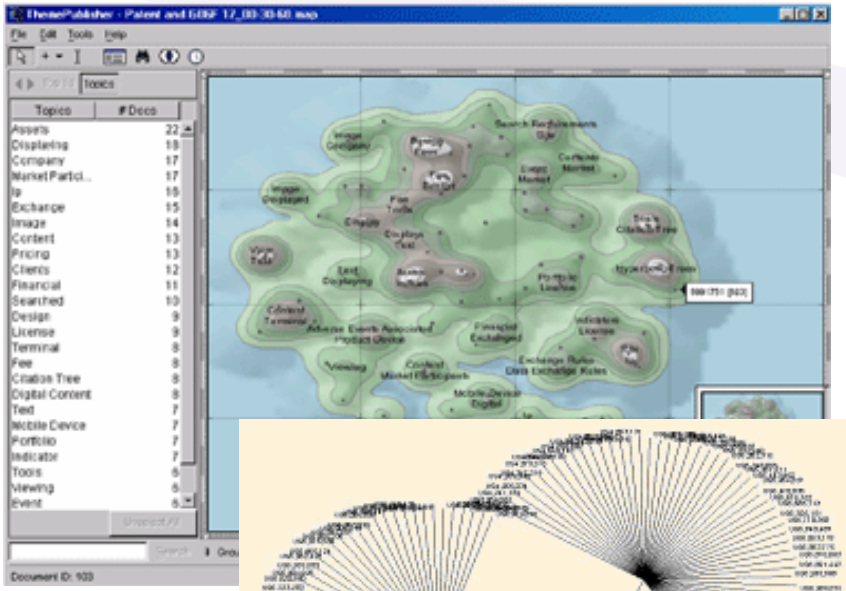
The <u>cost of technology progression</u> can be obtained by multiplying (A) and (B), probably best done on a yearly or lesser basis so that varying funding requirements can be captured.

Caution: Technology Forecasting is Fraught With Error

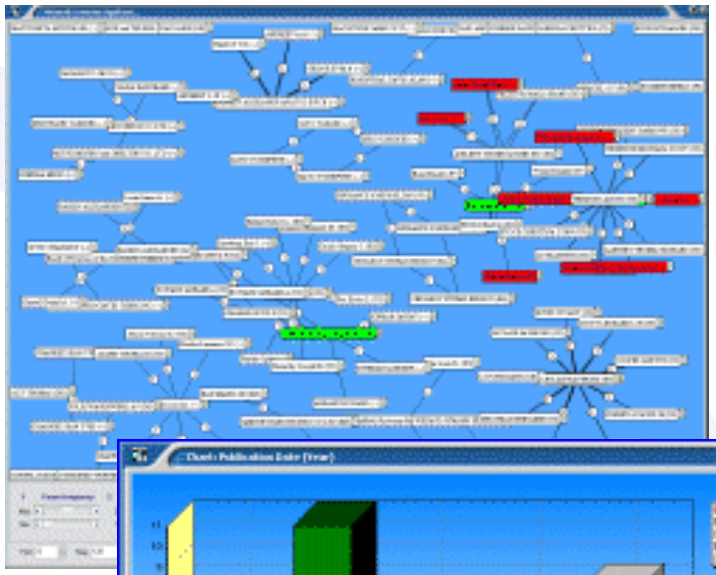


Visualization Methods For Determining Technological Maturity

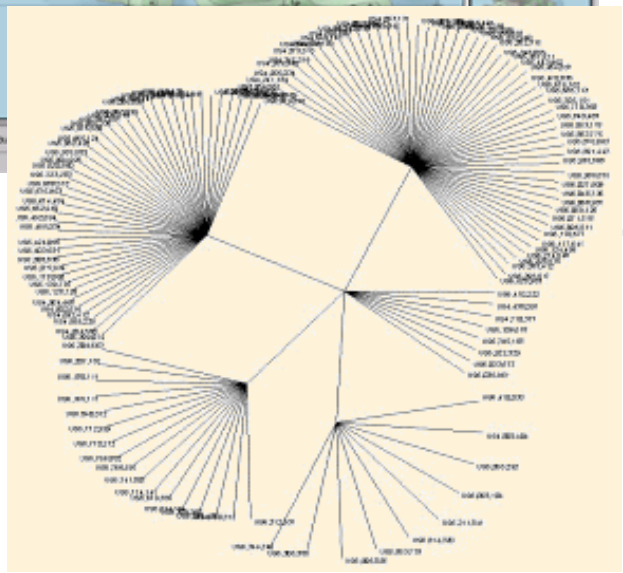
"How related are topics?"



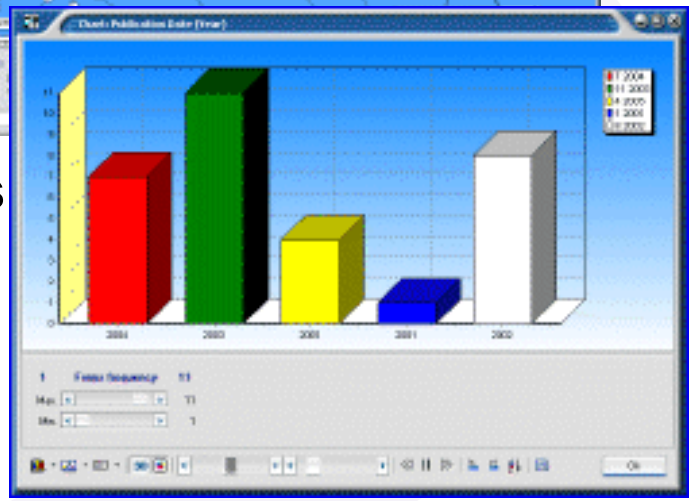
"What is the relation between inventions and companies?"



"How are patents related?"



"What is the patent rate?"



From http://www.infovis.net/printMag.php?num=167&lang=2

The 'Model Derived From Past Experience' Method

Approach

The model would be based on past experience conducting research projects. Questions to ask when obtaining data:

- How successful was the past outcome?
- Over how many years was research conducted?
- How much was spent each year?
- How many staff were involved each year?
- What was the budget profile?
- How novel was the technology?
- Were there stoppages in support?
- How volatile were requirements for this technology?
- What is the state of any industry producing something similar?
- What was the difficulty rating for the technology?
- How was research organized, as a separate lab, multiple teams, etc?
- Etc!

The 'Financial Forensics' Method

Approach

How much has it cost someone else?

- Profit-seeking firms price products so sunk costs can be recovered after an allowance for profit and other expenses. Some of those sunk costs are for R&D.

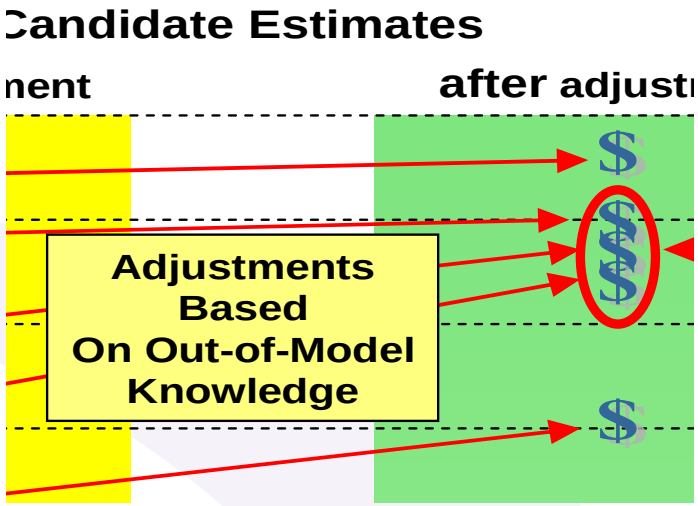
- Find firms' R&D expenses for generations of products by adopting competitive intelligence techniques.

Examples:

- A private rocket design & development costs $20-40M each
- New drugs cost about $897M each.

Combining Estimates: A Nuanced Approach

- Can the **past indicate anything about the future** or does cutting edge technology development operate according to an entirely dissimilar production function?
- How **can technologies be isolated for analysis**, if need be, from the systems into which they are integrated?
- How can a **"technology's readiness" level be precisely described**, so that the transition between earlier and later stages is correctly gauged?



- If necessary, how can **technology improvements be normalized** so that qualitative changes are differentiated from quantitative ones?
- Can lessons learned from one technology, such as civilian solar cells, **be applied to another**, such as spacecraft solar arrays?
- In order to bring about technology innovation, **what balance of inputs to the "R&D production function" is required**, including labor, capital equipment and dispensable material? Does this balance change as a technology matures?
- How can **market developments** (serendipitous discoveries, etc.) be controlled for to generalize lessons learned from a specific technology's evolution?

Analysis Considerations

- How can technologies be **isolated** for analysis, if need be, from the systems into which they are integrated?
- How can a technology's **"readiness level" be precisely described**, so that the transition between earlier and later stages is correctly gauged?
- If necessary, how can technology improvements be normalized so that **qualitative changes** are differentiated from quantitative ones?
- Can lessons learned from one technology, such as civilian solar cells, be applied to **another** such as spacecraft solar arrays?

Evolution of Technology Considerations

- Do **technologies bear any resemblance** to one another in their aspects of development? Or…
- Does cutting edge technology development operate according to an **entirely dissimilar production function**?
- Is there a difference between technologies whose "time has come" through **continuous development vs.** those that **serendipitously** arise "out of the clear blue sky"?
- Do **technology adoption 'curves' follow regular and repeated profiles?** Is the shape of these profiles consistent across generations?

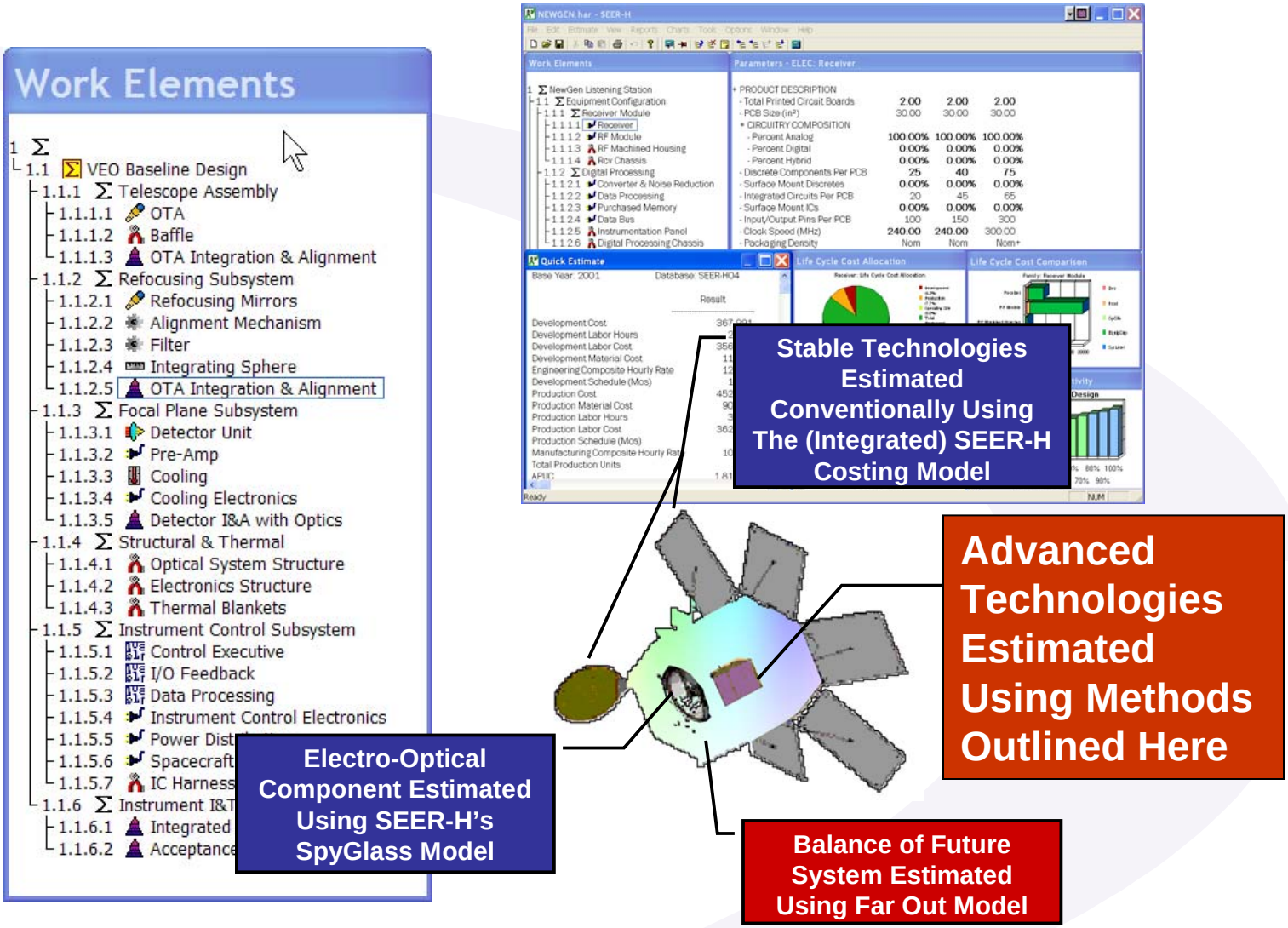
Market Considerations

- How does **cooperation with suppliers or competitors** sway development?
- Do **venture capital flows** indicate technologies that are about to mature, or do they in fact spur maturation?
- How do **market characteristics**, and the broader environment in which firms innovate, affect technological development?
- How can **market developments** be controlled for in generalizing the lessons learned from a specific technology's evolution?
- Do **technology adoption 'curves' follow regular and repeated profiles**? Is the shape of these profiles consistent across generations?
- All other factors aside, do **differing productivity levels within firms persist**, so that a company which has innovated well in the past will continue to do so in the future? What factors lead to this persistence?
- What impact do potential **commercial spin-offs** have on a technology?

Intra-Organizational Considerations

- What is the **difference between pure and directed** R&D? Do firms, over time, efficiently internalize their pure R&D costs into product pricing?
- What is the impact between R&D conducted entirely within one laboratory or **shared** between many external participants?
- Does innovation experience **returns to scale**? For instance, does a dollar spent at an early readiness level earn the same improvement as a dollar spent later on?
- In order to bring about technology innovation, what balance of inputs to the **"R&D production function"** is required, including labor, capital equipment and dispensable material? Does this balance change as a technology matures?

Advanced Estimating Methods In Context With Conventional Approaches



Who Are These Scientists and Innovators?

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